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Virtual Event @ Stony Brook University, March 18-22, 2021

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Time measurements using Ultra-Fast Silicon Detectors with a 120 GeV proton beam for the TOPSiDE concept at the Electron-Ion Collider

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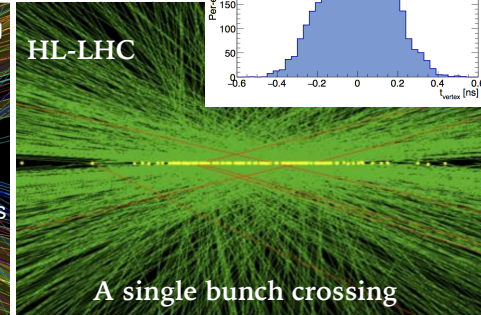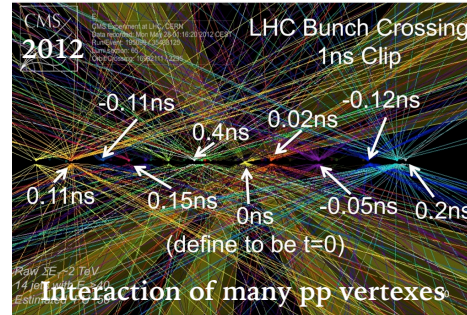University of California Santa Cruz

18 - 22 March 2021
Stony Brook, NY
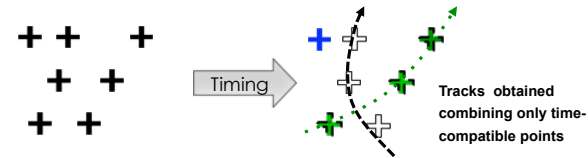
Outline

- ➤ Introduction to UFSDs
    - ➤ Motivation for Ultra-Fast Silicon Detectors (UFSD)
    - ➤ UFSD for TOPSiDE at the Electron-Ion Collider
    - ➤ Timing Measurements
- ➤ LGAD Test Setup
    - ➤ LGAD Measurement Setup
    - ➤ Testing of LGADs at the Fermilab Test Beam
- ➤ Results and Summary
- ➤ Outlook

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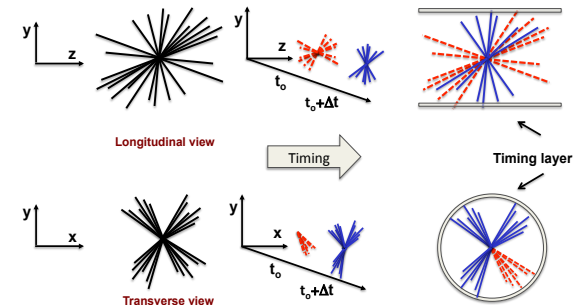
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Motivation for UFSDs

- ❖ One bunch crossing with ~50 overlapping events recorded by the CMS experiment in 2012
- ❖ The situation will substantially change at HL-LHC - the order of 150–200 events per bunch crossing
- ❖ The time-dimension improves the reconstruction process by considering only time-compatible hits
- ❖ Discarding those hits that cannot be associated to a track.
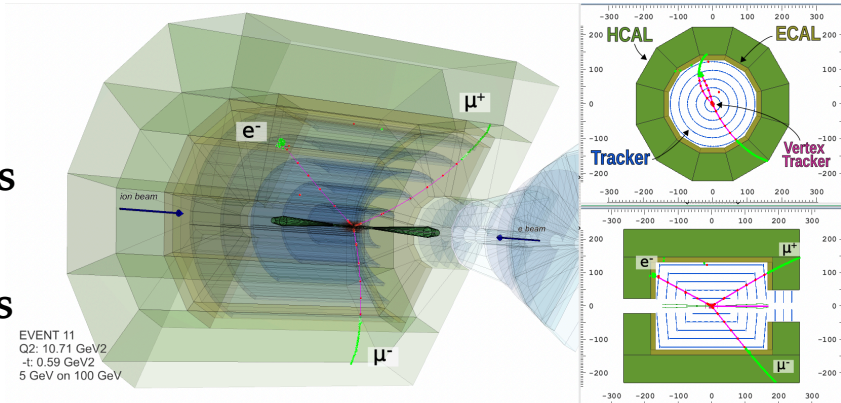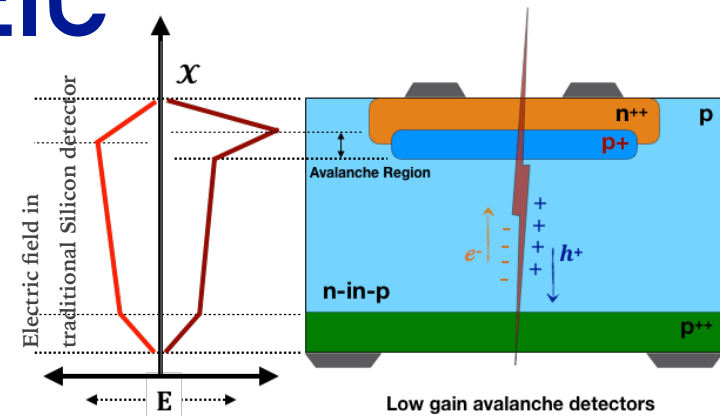- ❖ Particle Identification using Time-Of-Flight method

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Figure 1 Interaction time of many proton-proton vertexes happening in the same bunch crossing in the case of ~ 50 overlapping events. The vertexes are spaced 10's of pico seconds apart.

Figure 2 Left side: z-vertex distribution for a single bunch crossing at HL-LHC. Right side: the distribution of the interaction time at HL-LHC considering an average pile-up of 140 vertexes.

Figure 3 Effect of the inclusion of timing information in the event reconstruction at the hit level.

(1)

(2)

3

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UFSD for TOPSiDE at EIC

- ❖ **Low-Gain Avalanche Diode (LGAD)**
  - ❖ Internal gain layer (n^{++}- p^+ - p - p^{++})
- ❖ **High E-field in gain region**
  - ❖ Multiplication process
  - ❖ Provides gain of 10-70 w/o breakdown
- ❖ **Electron-Ion Collider: Polarized ep, eA collider**
  - ❖ Centre of mass energies up to ~140 GeV
  - ❖ Luminosity $\sim 10^{33}$-10^{34} cm^{-2}s^{-1}
- ❖ **Measurement and identification of particles**
  - ❖ Silicon tracker + Calorimeter - 5D info
- ❖ **Silicon sensor with time resolution ~ 10 ps**
  - ❖ kaon-pion separation up to 7 GeV/c

Low gain avalanche detectors

EVENT 11
Q2: 10.71 GeV2
-t: 0.59 GeV2
5 GeV on 100 GeV

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Timing Measurements

Time resolution of the Silicon detector can be expressed as contribution of,

$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{Jitter}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{TDC}^2$$

❖ **Timing capabilities of the silicon detector** are characterized by signal at preamplifier output and TDC binning

❖ **Time of arrival** is set when signal crosses the comparator threshold

❖ **Timing resolution** is measured as RMS of the timing difference (or TOF of a MIP) between the device-under-test (DUT) and the trigger.
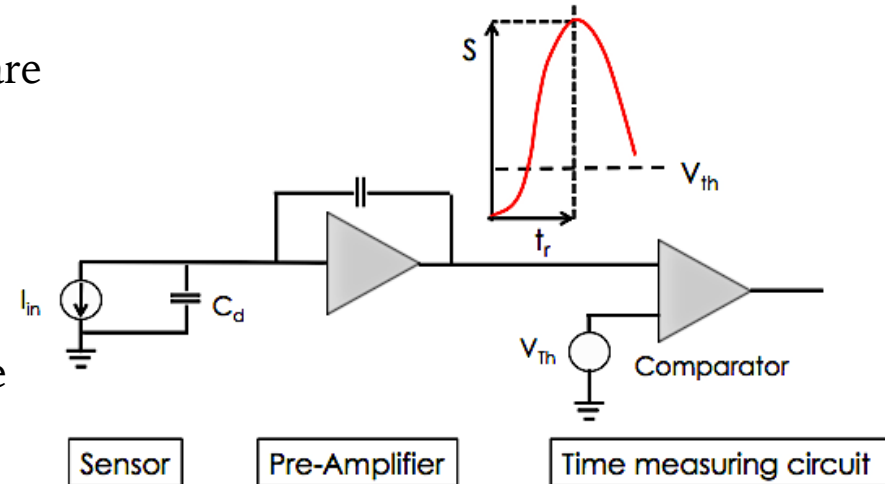
A simple time-tagging detector

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Timing Measurements

❖ **Time Walk:** the voltage value V_{th} is reached at different times by signals of different amplitude

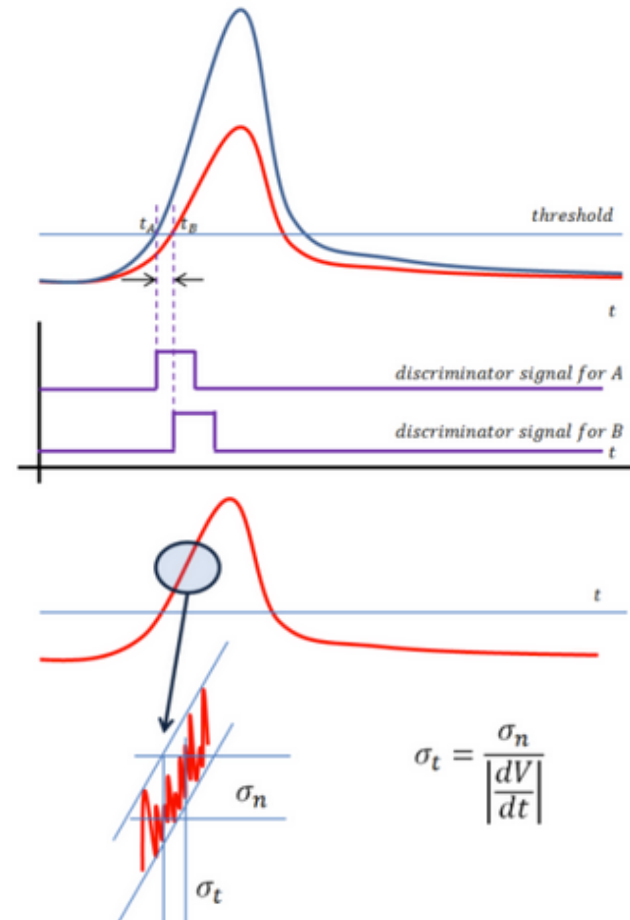$$\sigma_{TimeWalk} = \left[\frac{V_{th}}{\mathrm{d}v/\mathrm{d}t}\right]_{\text{RMS}}$$

Constant fraction discriminator (CFD) with TOA defined at % of signal amplitude reduces time-walk contribution

❖ **Jitter:** variation in time caused by the noise in the system

$$\sigma_{Jitter} = \frac{Noise}{\mathrm{d}V/\mathrm{d}t}$$

The noise is summed to the signal, causing amplitude variations

The predominant contribution to the timing resolution

threshold

t

discriminator signal for A

discriminator signal for B

t

$\sigma_t = \frac{\sigma_n}{\left|\frac{dV}{dt}\right|}$

σ_n

σ_t

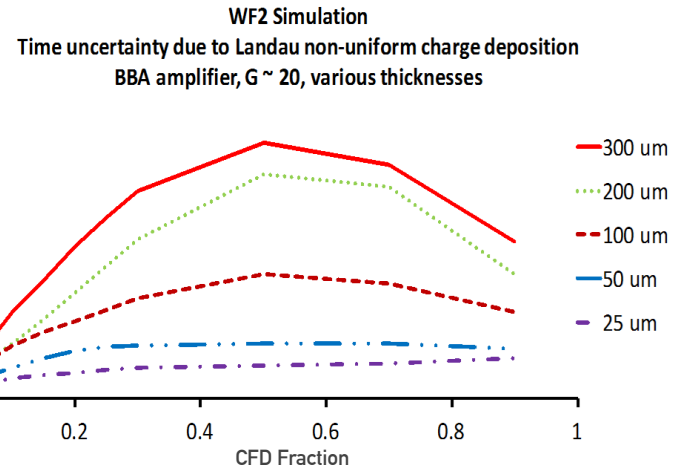Manoj Jadhav : 18-22 March 2021

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Timing Measurements

❖ **Landau Noise:** introduced by a particle's non-uniform charge deposition along its passage

Decreases with thickness of the sensor

Jitter and Landau noise contribute almost equally

❖ **Distortion:** The signal distortion is negligible in silicon for the saturated drift velocity and uniform weighting field.

❖ **TDC:** The TDC effect is minimal in most of the cases

$$\sigma_{TDC} = \frac{TDC_{bin}}{\sqrt{12}}$$

WF2 Simulation
Time uncertainty due to Landau non-uniform charge deposition
BBA amplifier, G ~ 20, various thicknesses

- 300 um
- 200 um
- 100 um
- 50 um
- 25 um

Thinner Sensor => faster rise time => larger slew rate

The time resolution is minimized by maximizing the slew rate dV/dt of the signal and minimizing the noise

We need large and short signals!

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LGAD Measurement Setup

❖ **β-Telescope**
  ❖ Lab bench setup with Sr^{90} source

❖ **Single channel readout board**
  ❖ 10×10 cm²; impedance of 50Ω
  ❖ Wide bandwidth 2 GHz and gain 10
  ❖ Total trans-impedance of 4700Ω
  ❖ The amplifier is followed by an external commercial amplifier with gain 10

❖ **Signal acquisition**
  ❖ High Voltage Power Supply CAEN DT1471ET
  ❖ KEYSIGHT E3620A DC low voltage power supply
  ❖ KEYSIGHT DSOS204A infiniium 4-Channels
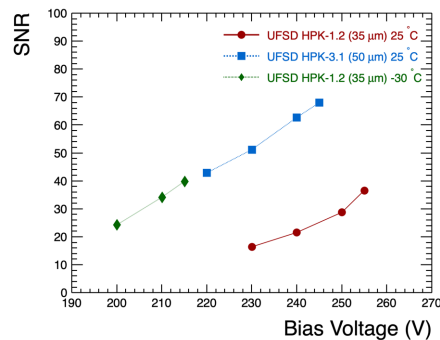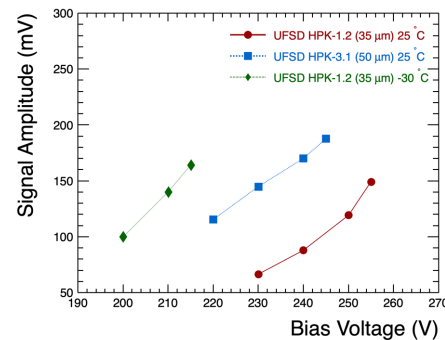 ❖ Measurements at -30 °C using FP89-ME Julabo Chiller
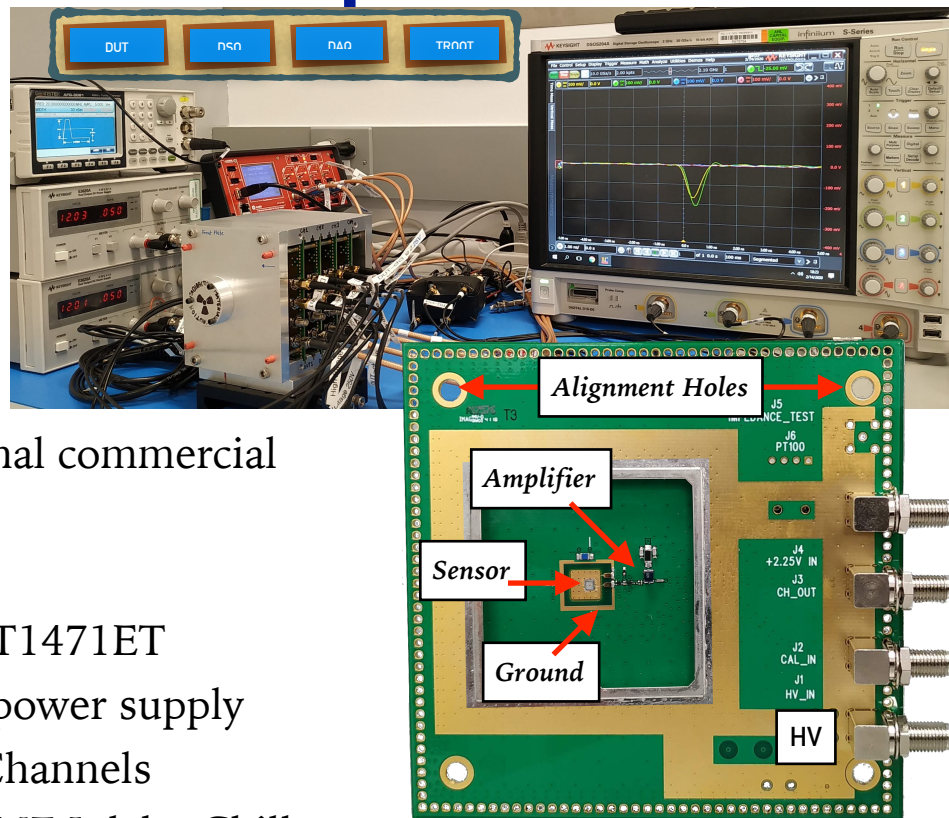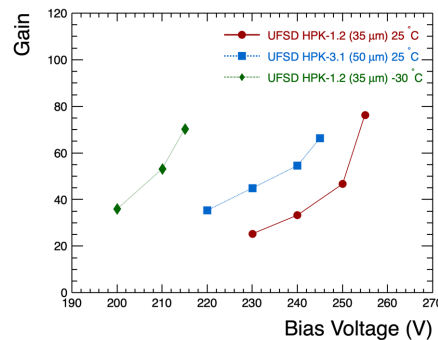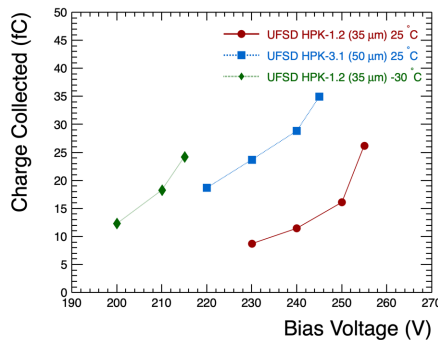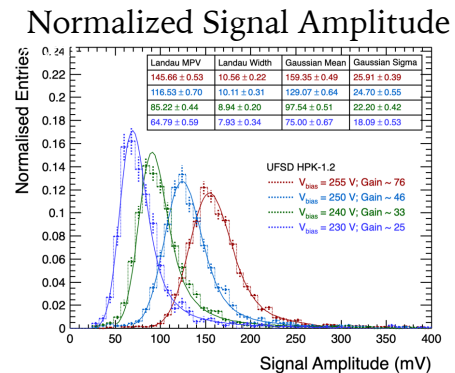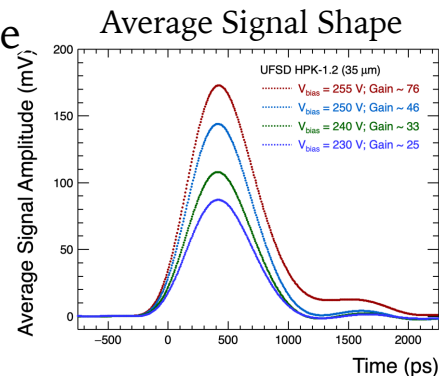
Fermilab Test Beam Set-up

❖ Proton Beam with momentum 120 GeV

❖ Sensors HPK 1.2 (35µm), 3.1(50µm) were tested

❖ In collaboration with UCSC and BNL groups

Alignment Box

Shielding

Beam

XYZ movement

Cold Box

LGAD Set-up

ATLAS FEI4 Telescope Planes

RD53A

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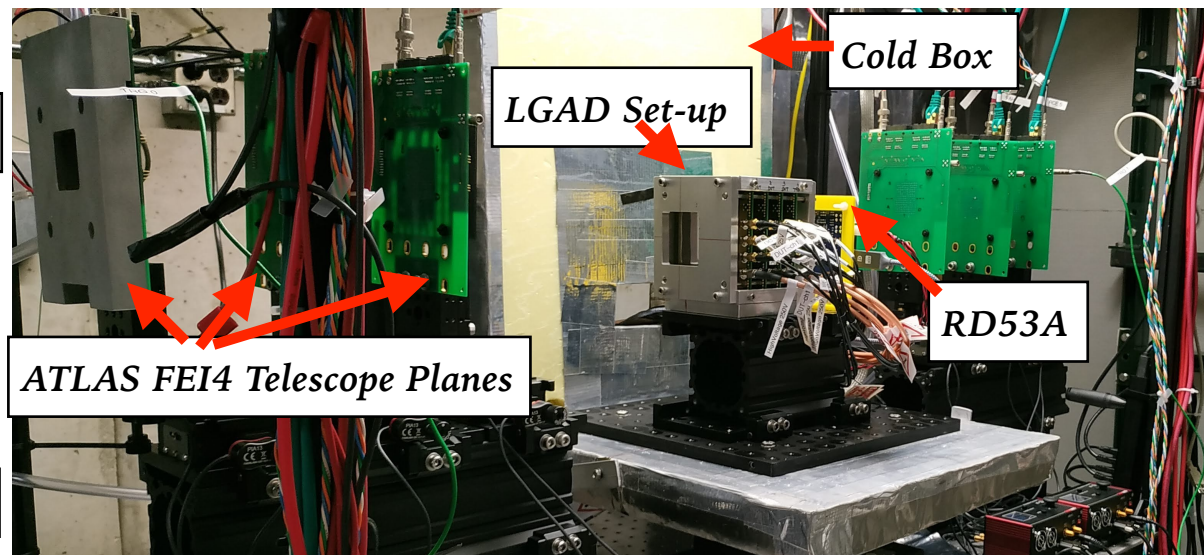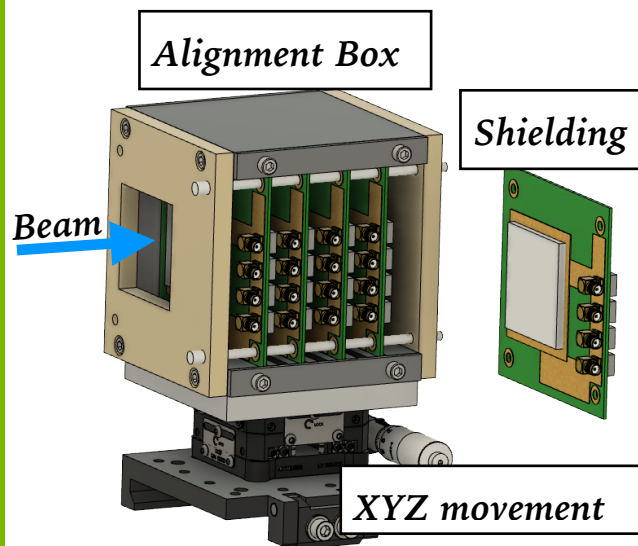
Results and Summary

- ❖ Normalized signal amplitude vs. Bias Voltage
- ❖ Charge Multiplication increases with bias voltage increasing the Gain
- ❖ Signal Amplitude, Signal to Noise Ratio, Jitter, Rise Time as function of voltage bias and temperature

Average Signal Shape

Normalized Signal Amplitude

Landau MPV	Landau Width	Gaussian Mean	Gaussian Sigma
145.66 ± 0.53	10.56 ± 0.22	159.35 ± 0.49	25.91 ± 0.39
116.53 ± 0.70	10.11 ± 0.31	129.07 ± 0.64	24.70 ± 0.55
85.22 ± 0.44	8.94 ± 0.20	97.54 ± 0.51	22.20 ± 0.42
64.79 ± 0.59	7.93 ± 0.34	75.00 ± 0.67	18.09 ± 0.53

Results and Summary

❖ Timing resolution for 3 layers of LGADs

❖ Timing resolution improves at low temperature but restricted by the lower breakdown voltage

❖ Very short rise time of ~350-400 ps were obtained

❖ Achieved **timing resolution of 14.31 ± 1.52 ps**

❖ M. Jadhav et al., arXiv:2010.02499; Accepted at JINST

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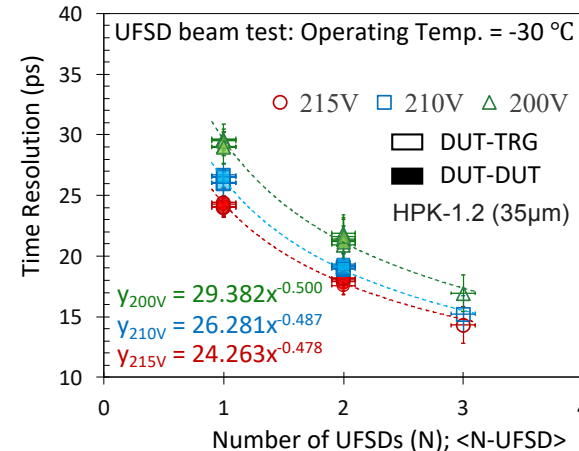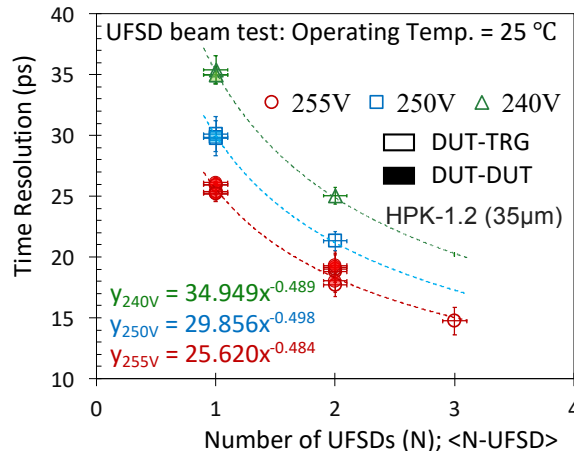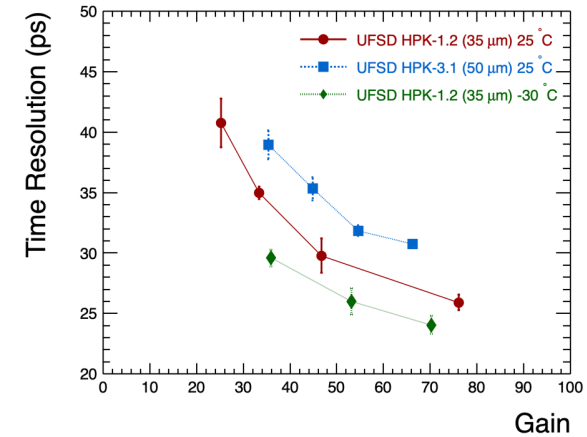
Outlook

Argonne Micro-Assembly Facility - clean room

- ❖ Probe Station
- ❖ Wire-Bonders
- ❖ 3D printer
- ❖ Thermal Chamber
- ❖ SmartScope ZIP for Metrology
- ❖ ATLAS telescope and LGAD setup

Ongoing Development

- ❖ Designing a telescope structure for multichannel readout system
- ❖ Upgrading DAQ from software based CFD to digitizer based: Beyond DSO trigger
- ❖ R&D of LGAD sensors and modules
  - ✓ Goal is to reach 10 ps of timing resolution
  - ✓ Testing CFD read-out boards designed at Argonne
  - ✓ Monolithic LGAD simulations and designing
- ❖ Analysis of data collected at Fermilab test beam facility with 120 GeV proton for different AC-LGADs with multi-channel read-out boards.
- ❖ Argonne is part of LGAD consortium for EIC

Thank You!

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